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June 9, 2003

Marlene H. Dortch, Esquire
Secretary
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: Petition for Reconsideration in ET Docket 98-153

Dear Ms. Dortch:

On May 21, 2003, the "Petition for Reconsideration of Multispectral Solutions, Inc." (the "Petition") was filed electronically in the above-referenced docket. Upon checking the Commission's Electronic Comment Filing System ("ECFS") today, we observed that Figure 1 on page 15 of the Petition is partially omitted, presumably due to a technical malfunction in the process. Attached is an identical Petition with Figure 1 in its entirety.

Should any questions arise with regarding to this matter, kind communicate with the undersigned.

Respectfully submitted,

Raymond G. Bender, Jr.
Counsel to Multispectral Solutions, Inc.

RGB/vll
Enclosure

cc: Ed Thomas
Julius Knapp
John Reed

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the matter of	)	
	)	
Revision of Part 15 of the Commission's Rules	)	ET Docket No. 98-153
Regarding Ultra-Wideband Transmission	)	
Systems	)	

To: **The Commission**

PETITION FOR RECONSIDERATION OF MULTISPECTRAL SOLUTIONS, INC.

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Dated: May 21, 2003

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SUMMARY

Multispectral Solutions, Inc. ("MSSI") submits this Petition for Reconsideration in ET Docket 98-153 to urge the Commission to find that low pulse repetition frequency ("PRF") Ultra-Wideband ("UWB") systems have less potential to cause interference that UWB devices operating at a high PRF. The Commission rejected this proposition in the *Memorandum Opinion and Order* ("*MO&O*") in this proceeding based on its reading of certain technical data furnished by the National Telecommunications and Information Administration ("NTIA"). MSSI submits, however, that the Commission misinterpreted relevant NTIA technical results which, when properly analyzed, fully support a finding that low PRF UWB systems uniformly have a lower interference potential than high PRF systems. MSSI urges the Commission to adopt this conclusion and, given the lack of interference from low PRF UWB devices, to permit any type of UWB device employing a low PRF to operate in the 3.1-10.6 GHz band.

Reconsideration of the *MO&O* based on the information contained in this Petition would serve the public interest. First, the Commission and courts repeatedly have noted the importance of basing FCC decisions on an accurate and complete record. Reexamining the results of NTIA's technical data and viewing them accurately and completely, as explained herein, can only lead to a better and more informed decision by the Commission. Second, UWB technology holds great promise for a vast array of new applications that will provide significant benefits for public safety, businesses and consumers. The Commission must adopt technical analyses which accurately reflect the actual interference potential of proposed UWB systems, and which do not unduly restrict the development and deployment of new UWB products and services. For reasons explained herein, any type of UWB devices employing a low PRF should be permitted to operate in the frequency range 3.1 to 10.6 GHz.

Before the

FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems	)))	ET Docket No. 98-153

To: **The Commission**

PETITION FOR RECONSIDERATION OF
MULTISPECTRAL SOLUTIONS, INC.

Multispectral Solutions, Inc. ("MSSI"), pursuant to Section 1.429 of the Commission's rules, hereby respectfully submits this Petition for Reconsideration ("Petition") of the *Memorandum Opinion and Order* in the above-captioned proceeding regarding Ultra-Wideband ("UWB") transmission systems.[1] MSSI urges the Commission to find that low pulse repetition frequency ("PRF") UWB systems have less potential to cause interference than UWB devices operating at a high PRF. The Commission rejected this proposition in the *MO&O* based on its reading of certain technical data furnished by the National Telecommunications and Information Administration ("NTIA"). MSSI respectfully submits, however, that the Commission misinterpreted relevant NTIA technical results which, when properly analyzed, fully support a finding that low PRF UWB systems uniformly have a lower interference potential than high PRF systems. MSSI urges the Commission to adopt this conclusion. Further, given the lack of

[1] Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems, *Memorandum Opinion and Order and Further Notice of Proposed Rule Making*, ET Docket No. 98-153, released March 12, 2003 (hereinafter "*MO&O*").

interference from low PRF UWB devices, the Commission should permit any type of UWB device employing a low PRF to operate in the 3.1-10.6 GHz band.

I. INTRODUCTION

MSSI is a recognized industry leader with nearly 15 years of experience in the development and deployment of UWB systems that provide a variety of communications, radar and geopositioning products and services. Dr. Robert J. Fontana, MSSI's president and founder, has been actively involved in the design and development of UWB systems, with particular emphasis on low probability of detection (LPD) applications, for over 19 years. He is a frequent invitee to the U.S. Government's Low Probability of Intercept Communications Committee (LPICC) to discuss ultra wideband technology issues. MSSI has used and applied UWB technology in the development of high-speed communications networks and data links; collision and obstacle avoidance radars; precision geolocation systems for personnel location and mapping; intelligent transportation systems (tags and electronic license plates); and other state-of-the-art UWB systems. MSSI's experience includes RF designs up to 40 GHz as well as high-speed digital processing systems extending beyond 500 Mb/s.

MSSI's clientele includes a wide variety of U.S. Government agencies, military organizations and commercial entities. Since the company's inception, MSSI has received more than 70 contract awards to develop and field UWB equipment for the U.S. Government and military. Each of these contracts has resulted in the development of UWB hardware and systems, many of which have undergone extensive test and evaluation by the Government.

UWB systems have been of prime importance to the military because they are capable of performing with low probability of detection (LPD). However, LPD performance is assured only by the use of low PRF systems, where energy buildup does not occur in an intercept receiver or, equivalently, in a victim receiver. MSSI has been developing and deploying UWB LPD systems for 15 years for a variety of communications, radar and geopositioning applications. Hence, MSSI has a particular expertise with respect to this feature of UWB technology.

MSSI previously asked the Commission to permit any type of UWB device employing a low PRF, *e.g.*, a vehicular radar system, to operate in the 3.1-10.6 GHz band. MSSI noted that given peak power constraints embodied in various Part 15 rules, the lower the PRF, the lower the average power levels and, hence, the lower the probability for potential interference to other services. MSSI also pointed to submissions from NTIA, Stanford/DOT and others[2] to show that low PRF systems, particularly those with PRFs less than a few hundred kHz, were particularly benign to extremely sensitive GPS receivers and had effects considerably less deleterious than even additive white Gaussian noise.

In the *MO&O*, the Commission denied MSSI's request to permit any type of UWB device employing a low PRF to operate in the 3.1-10.6 GHz band.[3] The Commission stated that the immunity of GPS receivers to low PRF interference does not necessarily apply to other radio systems using different receiver designs and modulation types.[4] In the *Further NPRM* portion of its decision, the Commission repeated its disagreement with MSSI's assertion that low PRF

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[2] Most recently, the Defense Advanced Research Projects Agency (DARPA), under the *Networking in the Extreme (NETEX)* initiative, conducted an extensive series of tests of the interference potential of wide classes of ultra wideband systems on the avionics equipment for an F/A-18. These tests also illustrated the low interference potential of low PRF UWB emissions vis-à-vis high PRF sources. DARPA Program Manager: Mr. Steve Griggs (703) 696-2312.

[3] *MO&O*, *supra*, at para. 42.

[4] *Id.*

systems have less potential to cause interference than UWB devices operating at a high PRF.[5] In fact, the Commission stated its belief that low PRF UWB systems can have a higher potential for causing interference than that of high PRF UWB systems, and it pointed to an NTIA publication to support this conclusion.[6]

For reasons discussed below, MSSI respectfully submits that the Commission has misinterpreted the NTIA data furnished in this proceeding. When properly evaluated, the NTIA results demonstrate that low PRF UWB systems have a lower potential to cause interference than UWB devices operating at a high PRF.[7]

II. DISCUSSION

The present Petition for Reconsideration addresses an error in the *MO&O* which may unfairly penalize UWB systems which have proven themselves to be low probability of interference. More specifically, in its *MO&O*, the FCC stated

> *With regard to MSSI's request to permit any type of UWB device employing a low PRF, e.g., a vehicle radar system, to operate in the 3.1-10.6 GHz, MSSI does not consider that the NTIA analysis for systems other than GPS demonstrated that the interference potential from a UWB transmitter may increase when lower PRFs are employed.[note 79]* [8]

and,

> *MSSI argues that low PRF systems have less potential to cause interference than UWB devices operating at a high PRF. We disagree. As demonstrated by NTIA, low PRF*

---

[5] *MO&O, supra,* at para. 154.

[6] *See Id.*, including the Commission's reference to NTIA Special Publication 01-43, *Assessment of Compatibility Between Ultrawideband Devices and Selected Federal Systems.*

[7] Although the Commission did not concur with MSSI that low PRF systems have less potential to cause interference than high PRF equipment, it did seek further public comment on MSSI's request. Among other things, the Commission proposed to amend the rules to permit the operation of any UWB product under the UWB standards currently designated for hand held devices as long as the PRF does not exceed 200 kHz and the equipment employs a pulsed or an impulse modulation. MSSI plans to comment on this proposal and on the other questions raised by the Commission in the *Further NPRM* concerning this issue.

[8] *MO&O, supra*, at para. 42

UWB systems can have a higher potential for causing interference than that of high PRF UWB systems. [9]

FCC cited reference [note 79] refers to the First Report and Order[10]:

> *NTIA investigated the potential interactions of proposed UWB systems on 15 U.S. Government systems operating between the frequencies of 960 and 5650 MHz. The systems investigated included Distance Measuring Equipment (DME) interrogator airborne receiver, DME ground transponder receiver, Air Traffic Control Radio Beacon System (ATCRBS) air transponder receiver, ATCRBS ground interrogator receiver, ARSR), Search and Rescue Satellite (SARSAT) ground station land user terminal, ASR, Next Generation Weather Radar (NEXRAD), Maritime Radar, Fixed Satellite Service (FSS) earth stations, CW and Pulsed Radar Altimeters, Microwave Landing Systems (MLS), and Terminal Doppler Weather Radar (TDWR). Table 6 denotes these systems and their frequency band of operation and summarizes NTIA's conclusions of emission limits necessary to preclude interference from a UWB transmitter operating at a height of 2 or 30 meters. The maximum UWB EIRP is the maximum signal level that NTIA calculated at which a UWB transmitter could operate without causing interference to the system when the UWB is allowed unrestricted outdoor operation independent of the UWB's pulsewidth, PRF, or other modulation schemes or the nature of its intended operation (e.g. radio determination or communication). Where there was a difference due to the PRF of the UWB emission, we have included the results from the PRF that required the UWB emissions to be reduced to the lowest level. In the column for 30 meters, "Not Applicable" indicates that the particular scenario would involve a UWB transmitter on a fixed antenna tower at the same altitude as the airborne victim, which would not be likely.* [11]

and,

> ARSR-4. *This system is used by the FAA and DOD to monitor aircraft during enroute flight to distances of beyond 465 km (250 nautical miles). NTIA used a protection criterion of an interference-to-thermal noise ratio of -10 dB, i.e., I/N = -10 dB, while the current protection criteria in ITU-R Recommendation M.1463 is for an I/N of -6 dB for both radionavigation and radiolocation applications of radar.* [208] *NTIA calculated that low PRF operations of UWB devices, even near ground level, must be limited to -60 dBm EIRP to protect the ARSR-4. We note that the emission limits being required for emissions in the GPS bands are adequate to protect ARSR-4 operations.* [12]

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[9] *MO&O, supra*, at para. 154

[10] Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems, *First Report and Order*, ET Docket No. 98-153, released March 22, 2002 (hereinafter "*R&O*").

[11] *R&O*, supra, at para. 124.

[12] *R&O*, supra, at para. 131

The NTIA investigation referred to by the FCC is NTIA Special Publication 01-43.[13] We respectfully submit that the FCC has misinterpreted the NTIA results as shown in the following discussion.

In Section 4.3 of NTIA Special Publication 01-43, the NTIA summarizes the test results for the ARSR-4 Radar which was referenced by the FCC as an example of how "*the interference potential from a UWB transmitter may increase when lower PRFs are employed*". These results were summarized in Tables 4-7, 4-8, 4-9 and 4-10 of Section 4.3 reproduced below.

TABLE 4-7
Non-Dithered UWB Signal into ARSR-4 Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.6	-59.6	-18.3	5.5
.01	-1.6	-59.6	-18.3	5.5
.1	-1.6	-59.6	-18.3	5.5
1	0.0	-61.2	-19.9	6.1
10	0.0	-61.2	-19.9	6.1
100	0.0	-61.2	-19.9	6.1
500	0.0	-61.2	-19.9	6.1

TABLE 4-8
Dithered UWB Signal into ARSR-4 Receiver (UWB Height = 2m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.6	-59.6	-18.3	5.5
.01	-1.6	-59.6	-18.3	5.5
.1	-1.6	-59.6	-18.3	5.5
1	-1.6	-59.6	-18.3	5.5
10	-1.6	-59.6	-18.3	5.5
100	-1.6	-59.6	-18.3	5.5
500	-1.6	-59.6	-18.3	5.5

[13] Brunson, L.K. et al., "Assessment of Compatibility between Ultrawideband Devices and Selected Federal Systems," NTIA Special Publication 01-43, U.S. Department of Commerce, National Telecommunications and Information Administration, January 2001.

TABLE 4-9
Non-Dithered UWB Signal into ARSR-4 Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	-1.6	-80.0	-38.7	>15
.01	-1.6	-80.0	-38.7	>15
.1	-1.6	-80.0	-38.7	>15
1	0	-81.6	-40.3	>15
10	0	-81.6	-40.3	>15
100	0	-81.6	-40.3	>15
500	0	-81.6	-40.3	>15

TABLE 4-10
Dithered UWB Signal into ARSR-4 Receiver (UWB Height = 30 m)

PRF (MHz)	BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
001	-1.6	-80.0	-38.7	>15
.01	-1.6	-80.0	-38.7	>15
.1	-1.6	-80.0	-38.7	>15
1	-1.6	-80.0	-38.7	>15
10	-1.6	-80.0	-38.7	>15
100	-1.6	-80.0	-38.7	>15
500	-1.6	-80.0	-38.7	>15

In NTIA Table 4-7, it is seen that, for low PRFs (below 1 MHz), the maximum permitted UWB EIRP can be 1.6 dB *higher* than for high PRFs (above 1 MHz). However, it is also extremely important to note that this is on an *average* power basis (dBm/MHz RMS).

Note that RMS and PEAK powers are related by the equation

$$P_{RMS} = P_{peak}\delta$$

where δ is the pulse duty cycle given by $\delta = \tau R$. Here, τ is the pulse duration and R is the UWB pulse repetition frequency (PRF) or rate.

Thus, $P_{peak} = \dfrac{P_{RMS}}{\tau R}$ or $10\log P_{peak} = 10\log P_{RMS} - 10\log R - 10\log\tau$.

Since τ is a fixed constant for a given UWB waveform, the peak power is seen to be inversely proportional to the PRF for a given measured RMS power.

Going back to NTIA Table 4-7, and using the above relationships, the PEAK values associated with these maximum permitted EIRP numbers are as shown in the following Table:

Table 1. ARSR-4 Performance (Peak Powers)

UWB PRF (MHz)	Max. EIRP (Non-Dithered) (dBm/MHz **peak**)
0.001	$-59.6 - 10 \log 10^3 - 10 \log \tau = \mathbf{-89.6 - 10 \log \tau}$
0.01	$-59.6 - 10 \log 10^4 - 10 \log \tau = \mathbf{-99.6 - 10 \log \tau}$
0.1	$-59.6 - 10 \log 10^5 - 10 \log \tau = \mathbf{-109.6 - 10 \log \tau}$
1	$-61.2 - 10 \log 10^6 - 10 \log \tau = \mathbf{-121.2 - 10 \log \tau}$
10	$-61.2 - 10 \log 10^7 - 10 \log \tau = \mathbf{-131.2 - 10 \log \tau}$
100	$-61.2 - 10 \log 10^8 - 10 \log \tau = \mathbf{-141.2 - 10 \log \tau}$
500	$-61.2 - 10 \log (5\text{x}10^8) - 10 \log \tau = \mathbf{-148.2 - 10 \log \tau}$

Thus, the NTIA shows that not only are low PRF UWB emissions (0.001, 0.01 and 0.1 MHz) more difficult to detect, but the PEAK power of the 1 kHz UWB emitter used in the example was actually -89.6 – (-148.2) = 58.6 dB, or *725,000 times higher* than the peak power of the 500 MHz PRF UWB source. In other words, despite this significantly higher peak power, the low PRF UWB emitter caused less interference.

Note that identical conclusions can be reached for NTIA Tables 4-8, 4-9 and 4-10 for the ARSR-4 radar system. These results are typical of all of the cases where the protection criteria was based on an average (RMS) interference power.

The NTIA also considered protection criteria based upon a peak interference power constraint. Typical of these examples is the SARSAT Ground Station Land User Terminal (LUT) at 1544-1545 MHz. The maximum EIRP (dBm/MHz RMS) required to meet the protection criteria with a peak interference power constraint was shown in NTIA Table 4.37b (page 4-35).

TABLE 4-37b
Non-Dithered UWB Signal into SARSAT LUT Receiver (UWB Height = 2m)

PRF (MHz)	Peak BWCF (dB)	Maximum Permitted UWB EIRP (dBm/MHz) RMS	Delta Reference Level (dB)	Distance (km) Where Permitted UWB EIRP Equals -41.3 dBm/MHz RMS
.001	35.0	-104.4	-63.1	>15
.01	25.0	-94.4	-53.1	12.0
.1	15.0	-84.4	-43.1	7.3
1	5.0	-74.4	-33.1	4.2
10	0.0	-69.4	-28.1	3.1
100	0.0	-69.4	-28.1	3.1
500	0.0	-69.4	-28.1	3.1

For this example, the NTIA also computed the distance (km) where the permitted UWB EIRP equals -41.3 dBm/MHz RMS (last column of Table 4-37b). At a 1 kHz PRF, the peak bandwidth correction factor (BWCF) was found to be 35.0 dB; whereas at a 1 MHz PRF the peak BWCF was found to be 5.0 dB. Thus, in this NTIA example, the 1 MHz UWB signal was required to have a 30 dB (1000 times) higher peak power than the 1 kHz UWB signal in order to achieve the same RMS EIRP. Since line-of-sight range was considered in these examples, a factor of 1000 in peak power should have resulted in a factor of $\sqrt{1000} = 31.6$ in range. Thus, since the 1 MHz UWB signal had a range of 4.2 kilometers; the 1 kHz UWB signal (for the same level of interference), should have had a range 31.6 times greater, or greater than 132 kilometers. The fact that it didn't, but rather only exceeded 15 kilometers, is indicative of the fact that the lower PRF created substantially less interference in the SARSAT LUT receiver – even on a peak power basis.

Again, the NTIA's SARSAT LUT example above is typical of all of the cases where the protection criteria was based on a peak interference power.

It is also important to note that the FCC, in specifying its peak and average constraints for Part 15 devices (and, in particular, those constraints for UWB devices under Subpart F), actually itself encourages the use of low PRF UWB emissions. Appendix A below fully illustrates this.

III. GRANT OF THIS PETITION WOULD SERVE THE PUBLIC INTEREST

MSSI respectfully submits that reconsideration of the *MO&O* based on the information contained in this Petition would serve the public interest. The Commission repeatedly has emphasized the importance of basing its decisions on an accurate and complete record.[14] Indeed, the Commission has noted that the development of "an accurate and complete record can only lead to a better and informed decision by the Commission."[15] For this reason, the Commission frequently accepts further pleadings containing new information in order to have as complete and accurate record as possible.[16] The courts, too, have stressed that agency decisions must be predicated on a record that is factually accurate and complete.[17] Thus, the Commission should reconsider the results of NTIA Special Publication 01-43 in light of MSSI's analysis set forth herein, and it should revise accordingly its findings regarding the relative interference potential of low and high PRF UWB systems.

Moreover, the Commission has noted repeatedly that UWB technology holds great promise for a vast array of new applications that will provide significant benefits for public safety, businesses and consumers.[18] Although the Commission has proceeded cautiously in this

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[14] *Application of Ameritech Michigan*, 12 FCC Rcd. 3309, 3323 (1997); *Amendment of Section 73.202(b), Table of Assignments, FM Broadcast Stations,* MM Docket NO. 00-123, 16 FCC Rcd. 8868, 8869 (2000)

[15] *Carriage of the Transmissions of Digital Television Broadcast Station; Amendments of Part 76 of the Commission's Rules*, 13 FCC Rcd. 22746, 22747 (1998); *see also Implementation of the Satellite Home Viewer Improvement Act of 1999*, 15 FCC Rcd. 12588, 12589 (2000).

[16] *Radio Perry, Inc.*, 11 Rcd 10564, 10564 n.2 (1996); see also *Costa de Oro Television, Inc.*, 15 FCC Rcd 12637, 12641 (2000).

[17] *See generally., Bonneville International Corp. v. Peters*, 153 F. Supp.2d 763 (E.D. Pa 2001).

[18] *See e.g.,* Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems, *First Report and Order*, ET Docket No. 98-153, 17 FCC Rcd 7435, 7436 (2002) ("*First Report and Order*"); *MO&O* at ¶ 5.

docket in order to protect existing services from harmful interference, it also has observed that it must not unnecessarily constrain the development of UWB technology.[19] For this reason, it plainly serves the public interest for the Commission to adopt technical analyses which accurately reflect the actual interference potential of proposed UWB systems, and which do not unduly restrict the development and deployment of new UWB products and services. As demonstrated herein, low PRF UWB systems would not cause interference to other services, and therefore any type of UWB device employing a low PRF should be permitted to operate in the frequency range from 3.1 to 10.6 GHz.

CONCLUSION

MSSI respectfully requests that the FCC reconsider its views regarding the relative interference potential of low versus high PRF UWB systems. MSSI also urges the Commission to permit any type of UWB device employing a low PRF to operate in the 3.1-10.6 GHz bands.

Respectfully submitted,

MULTISPECTRAL SOLUTIONS, INC.

By /s/ Robert J. Fontana, Ph.D.
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May 21, 2003

[19] *First Report and Order*, 17 FCC Rcd at 7436.

Appendix A

FCC Peak and Average Constraints Favor Low PRF Systems

Let P_{peak} be the full bandwidth peak power of an ultra wideband (UWB) waveform, and let τ be the waveform's pulsewidth and R its average pulse repetition frequency (PRF). We first consider the case in which there are no lines in the power spectral density; i.e., the case in which the UWB signal is either dithered in time or the modulation is chosen to eliminate the spectral line components.

The average power, P_{ave}, of the waveform is given by the relationship

$$P_{ave} = P_{peak} \tau R \tag{1}$$

where the product τR is the pulse duty cycle.

Now, suppose that this signal is measured in a resolution bandwidth of B_R. The fraction of the total average power contained in this measurement bandwidth, P_{ave}^m, is given by

$$P_{ave}^m = P_{ave} \frac{B_R}{B_P} \tag{2}$$

where B_P is the instantaneous pulse bandwidth. Since $B_P \approx 1/\tau$, (2) can be rewritten as

$$P_{ave}^m = P_{ave} \tau B_R = P_{peak} \tau^2 R B_R . \tag{3}$$

Next consider the peak power as measured in the resolution bandwidth B_R. For $R < B_R$, each pulse is separate and discrete at the output of the measurement filter. Thus, by conservation of energy arguments,

$$P_{peak} \tau \left(\frac{B_R}{B_P} \right) = P_{peak}^m \tau_R \tag{4}$$

where (B_R/B_P) is the fraction of energy seen by the filter, $P_{peak}\tau$ is the full bandwidth energy in a single pulse, and $P_{peak}\tau_R$ is the single pulse energy at the output of the measurement filter.

Thus, for $R < B_R$,

$$P_{peak}^{m} = P_{peak}\tau^2 B_R^2 . \tag{5}$$

Conversely, for $R > B_R$, the measurement filter integrates approximately $R\tau_R$ pulses during its impulse response duration τ_R. Thus, the maximum peak signal value is roughly $R\tau_R$ times larger than the measured peak for a single pulse (eq. (5)), or

$$P_{peak}^{m} = R\tau_R P_{peak}\tau^2 B_R^2 = P_{peak}\tau^2 RB_R . \tag{6}$$

That is, at high PRFs, the measured peak and average values (in a narrower bandwidth than the UWB pulse) are approximately equal. Also note that, for $R<B_R$ (i.e., at low PRFs), the measured peak-to-average ratio at the output of the measurement filter is simply B_R/R.

In summary, the measured average and peak values are given by the relationships:

$$P_{ave}^{m} = P_{peak}\tau^2 RB_R$$

$$P_{peak}^{m} = \begin{cases} P_{peak}\tau^2 B_R^2 & \text{for } R < B_R \\ P_{peak}\tau^2 RB_R & \text{for } R > B_R \end{cases} . \tag{7}$$

Now the FCC mandates (47 CFR Part 15, Subpart F) that the average emissions from a UWB waveform satisfy

$$P_{ave}^{m} \le 75nW \text{ in a 1 MHz bandwidth}$$

equivalent to 500 μV/m at 3 meters; and that the peak emission[20] satisfy

$$P^{m}_{peak} \leq 1mW \text{ in a 50 MHz bandwidth}$$
$$\equiv 400nW \text{ in a 1 MHz bandwidth.}$$

Thus, for a 1 MHz measurement bandwidth (B_R=1 MHz),

$$P_{peak}\tau^{2}R \leq 75x10^{-15} \text{ Joules}$$

$$P_{peak}\tau^{2} \leq 4x10^{-19} \text{ Joule-sec for } R<B_R$$

$$P_{peak}\tau^{2}R \leq 400x10^{-15} \text{ Joules for } R>B_R. \tag{8}$$

Note that the third inequality is always satisfied when the first is satisfied; thus, the peak power in a high data rate system ($R>B_R$) is always limited by the FCC average constraint. Inequality relationships (8) are shown plotted in Figure 1 below.

[20] From FCC 47 CFR 15.521(g), "[i]f a resolution bandwidth other than 50 MHz is employed, the peak EIRP limit shall be 20 log (RBW/50) dBm where RBW is the resolution bandwidth in megahertz that is employed." However, as seen from Equation (7), the actual measured peak value depends upon the PRF.

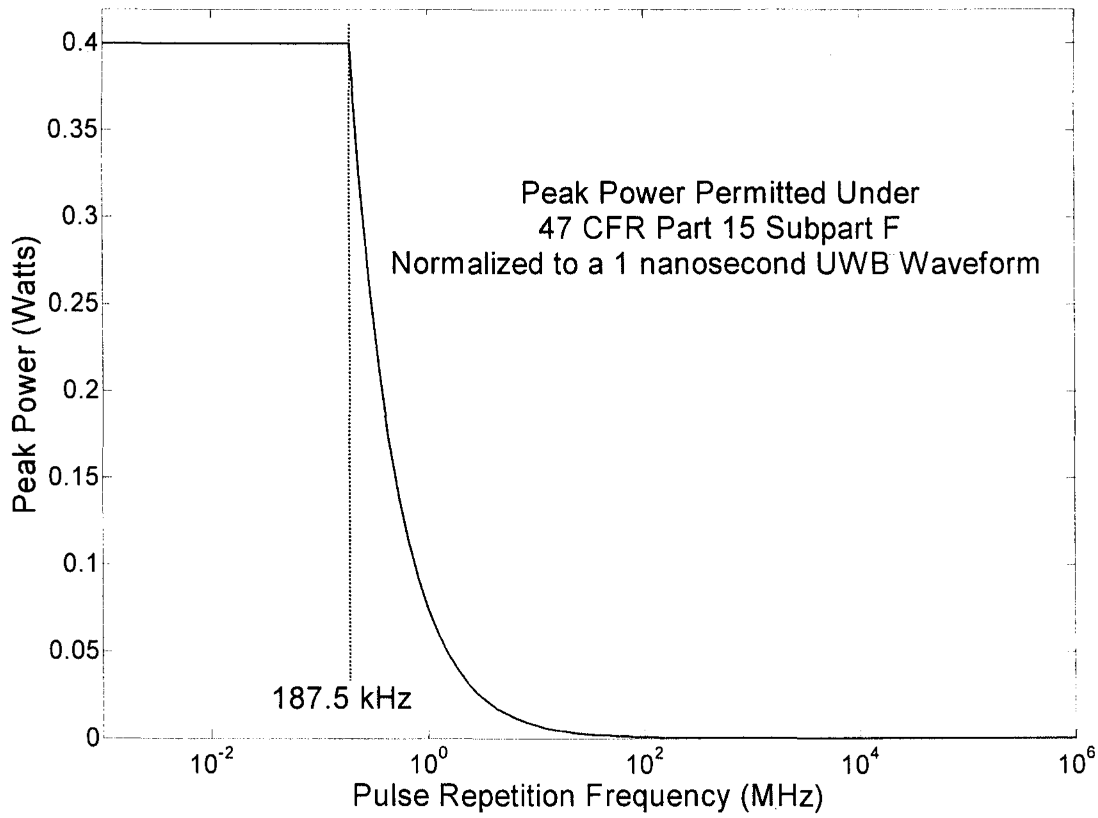

Figure 1. Inequality Constraints on $P_{peak}\tau^2$ (τ=1ns)

Note that, for PRFs less than 187.5 kHz, the peak power is limited by the FCC peak constraint; whereas for higher PRFs, the peak power is limited by the FCC average constraint. For UWB emissions having spectral lines (e.g., constant PRF waveforms), it is straightforward to show that the third inequality in (8) is given by the relationship

$$P_{peak}^{m} = P_{peak}\tau^{2}R^{2} \leq 400x10^{-9} \text{ Watts for } R>B_R. \tag{9}$$

In addition, the measured average power is equal to the measured peak power since a spectral line appears as a continuous wave (CW), constant envelope waveform. (Recall that a spectrum analyzer, as a frequency selective voltmeter with a peak detector, will measure both values the same.) Thus, in a 1 MHz resolution bandwidth,

$$P_{ave}^{m} = P_{peak}^{m} = P_{peak}\tau^{2}R^{2} \leq 75x10^{-9} \text{ Watts for all } R>B_R. \tag{10}$$

Once again it is observed that the average constraint dominates.

Conclusion

As seen from the above equations (e.g., equation (7)), a high PRF UWB emission creates both higher average and higher peak outputs in a measurement filter or victim receiver than does a low PRF UWB emission.

In addition, it is a simple consequence of FCC Part 15 emission limits, and specifically the limits on ultra wideband emissions imposed under Subpart F, that low PRF emissions are permitted higher peak powers than high PRF emissions under the current law (cf. Figure 1).

It is a further consequence of Part 15 Subpart F emission limits, that low PRF waveforms (i.e., PRFs below 187.5 kHz) are limited in peak power irrespective of the actual PRF. In other words, the average emission power goes to zero as the PRF (and pulse duty cycle) goes to zero. Thus, under the new Subpart F, the FCC correctly protects victim receivers from the deleterious effects of high PRF waveforms. Indeed, the regulations impose substantial power penalties on the use of high PRF systems. On the other hand, these same regulations also limit the maximum permissible peak power of a low PRF UWB waveform.

Hence, the FCC by its own regulations acknowledges that low PRF UWB systems are less interfering than high PRF UWB systems.